NEW OAKS FOR THE URBAN ENVIRONMENT:
PROPAGATION AND SELECTION OF HYBRID OAKS

A Thesis

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Master of Science

by

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ABSTRACT

Oak trees are one of the most desirable landscape trees in North America because of their wide distribution, great ecological and aesthetic value. Yet, plant propagators have not been able to select oak trees with desirable physiological and ornamental features because vegetative propagation was quite difficult. With new techniques developed at Cornell University, selection within the white oak group has become possible. This study aimed at propagating hybrid oak crosses made between oaks native to New York Stateusing pollen collected all over the world. The primary objective was to test and better understand the layering propagation method combining rejuvenation, etiolation and plant hormone stimulation and then select individuals with both alkaline tolerance to urban soil and good growth vigor for urban landscape use.

Approximately 360 hybrid oaks created during 2004 through 2006 were propagated twice in 2009 and 2010. Techniqueswere modified during propagation to better achieve better success. Due to these changes the percentage of new shootslost due to propagation treatment decreased 26%. Different rootabilities were observed among different hybrid types. Comparatively, female parents of stock plants had a stronger effect on the rootability than the male parent. Among the female parents, *Quercus xwarei* 'Long' REGAL PRINCE and *Quercus macrocarpa* had the highest rooting percentages, *Quercus bicolor* and *Quercus macrocarpa* 'Ashworth Strain' were intermediate and *Quercus muehlenbergii* was the hardest one to be propagated.

There was a significant loss during the first winter of newly propagated oaks after harvested in fall. Those that survived were then used to conduct an alkaline tolerance evaluation in soil pH8.0 with a control treatment of soil pH6.0 in open field and in the greenhouse respectively,during

2010 and 2011. Growth was evaluated and alkaline tolerance rating was measured using a SPAD meter was taken to determine the ability to function in alkaline soil. Some plants grew equally well or even better in alkaline soil, while some other plants showed poor growth and chlorotic symptoms.

Consistency can be found throughout the plants propagated in two years. However, due to the physiological features of plants, longer period of observation and further testing is needed to prove that individuals selected from new hybrids have consistent alkaline tolerance and may be very valuable in the urban landscape.

BIOGRAPHICAL SKETCH

Xian Gao was born in Shaanxi Province in 1986, and grew up in Xinjiang with her grandparents before she was brought to Beijing by her parents when she was six years old. She spent 12 years in Beijing from elementary school to high school then moved to Wuhan for College with an undergraduate major in Landscape Architecture at Huazhong Agricultural University in 2004. After getting a Bachelor degree, Xian flew over half of the earth and finally entered her dream school Cornell. Under the instructions and guidance of Dr. Nina Bassuk, she started her life of three years as an international student, enjoyed learning, doing research, and making new friends in the whole new world.

This thesis is dedicated to my parents.

I would never become who I am without their love, support and spirit.

ACKNOWLEDGMENTS

I am deeply indebted to my advisor Dr. Nina Bassuk. I've been impressed by her optimism to life, enthusiasm to work, generous love and support to students, and sincerely appreciate the precious opportunity of being part of her group. Her guidance and encouragement has enabled me to complete this work. I am very grateful to my minor advisor Dr. Kenneth Mudge, for his support in research and guidance in person, from the beginning of plant propagation course throughout the whole process of my master's experience.

I was very lucky and grateful to have the opportunity to work with nearly 400 hybrid oaks created by Peter Podaras with the method developed by Dr. Naalamle Amissah. The help and technical support from Pat MacRae, the staff in Blue Grass Lane and the Ken Post Lab enabled me to complete this work.

During the three years in Ithaca, I got plenty of help and care from Xuemei's family, who made my Ithaca experience warm and happy. I would like to express my deep gratitude to Mr. Fan Pu for his unselfish love, care and support, andMr. Yi Zheng for his generous help whenever I need. My friends and family overseas in China, Canada and Europe also provided lots of encouragement and support, I am truly grateful to be loved.

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Indole-3-butyric Acid……………………………………………………………….IBA

Gibberellin Acid………………………………………………………………….GA_3

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

Oak trees, (Quercus spp. L), naturally occur over wide range in the northern hemisphere. There are 300-600 species found in North America, Asia, Europe and Africa (Files,1993). Because of the wide distribution, oaks can be found as both deciduous and evergreens, from seashores to inland, from cold temperate zone to tropics. Woody plants in genus Quercus have developed outstanding abilities to survive in various habitats. Oaks in high latitudes are cold tolerant, while those in other sites may be tolerant of salty, alkaline, acid, and waterlogged or droughty soil (Nixon1993).

The strength and high density (0.75g/cm^3) of oak wood makes for high-quality timber used for interior wood paneling, fine furniture, ships, and barrels. In Europe, oaks make up a large percentage of nursery materials made every year (Files, 1993). Moreover, oaks also provide habitat for other plants, animals, insects and microorganisms, which play an essential role in ecological systems (Files, 1993). Their economic, environmental, and ornamental values are widely emphasized in forestry, horticulture and landscape development.

Oak taxonomy can be controversial because of the different opinions held on the identification of hybrid or species. According to most botanists, plants in the oak family can be categorized into 2 sub-genera: *Quercus* and *Cyclobalanopsis*. *Quercus* includes white oaks, red (and black) oaks, and intermediate oaks etc. White oaks are widely distributed in Europe, North America and Asia. Red/black oaks are from North America, Central America and northern South America. The Intermediate oak group is native to Southwest United States and Northwest Mexico.

Cyclobalanopsis with common name of ring-cupped oaks is an evergreen tree native to eastern Asia. This group has been considered a distinct genus by some taxonomists (Nixon, 1993).

Oaks are usually monoecious, self-pollinating or cross-pollinatingnaturally propagated by acorns. Hybridization occurs freely within sub-genera, which has been an important source of variation in natural stands. However, propagators have not been able to take advantage of this natural variation to select desirable individuals because asexual propagation is quite difficult.

Progress in asexual propagation methods has been made during the last several years. By combining etiolation (banding, shading), rejuvenation, and the application of plant growth regulators, clonal propagation has shown to be possible. Etiolation, which means growing plants in the absence of light or in shaded conditions during new shoot growth, has proven to significantly increase adventitious root formation in cuttings and layering (Amissah,et al., 2009). Rejuvenation is widely used in vegetative propagation. Severely cutting back of the stock plants accomplishes this effect. Propagules taken from stock plants in their physiological juvenile phase (without the ability to flower) were found to be more likely to produce adventitious roots (Hartmann& Kester 2001). However, stock plants without the ability to flower alone does not assure good rooting from cuttings or layers taken from them. It is necessary to use shoots arising from the most proximal portion of the stem in order for rooting to be successful.

Stem cuttings from semi-hardwood shoots have been the most common asexual propagation approach that is being widely studied by researchers and growers. Species of *Q virginiana, Q cerris (Q petraea), Q pubescens, Q macrocarpa and Q robur* seedlings have been successfully propagated by semi-hardwood stem cuttings taken from young, juvenile stock plants. Moreover, treatments of plant hormones such as Indol-3-butyric Acid (IBA), and gibberellin (GA_3) during propagation were found to be beneficial in promote rooting percentage 6- to 7-fold on different species. It was observed that shoot numbers produced by stock plants have also increased (Struve, et al., 2010).

Grafting of oaks is difficult but has proven to be successfully in greenhouse and field reproductions with certain species. *Q coccinea* can be grafted on 2-year-old seedlings (Dirr and Heuser 2006). Cultivars *Q robur* are mostly pot-grafted on the seedlings rootstock of species. *Q suber* from Europe is shown to be compatible with species of *Q chrysolepis*, *Q kelloggii*, *Q douglasii*, and *Q engelmannii* in greenhouse experiments. *Q douglasii* from California has been propagated by a modified bark grafting technique on *Q lobata*. Grafting on mature rootstocks has been shown to be viable on several species such as *Q rubra*, but the approach is often constrained by delayed incompatibility between scion and rootstock due to the large genetic variability within oak species (Skinner, 1952; Hartmann & Kester, 1983; Coggeshall, 1993; Zaczek 2006). Shoots grafted on seedling rootstocks show higher survival rates than those from grafted on older wood. There is one report of increased rootability of cuttings taken from grafted seedlings (Zaczek 2006).

Besides traditional vegetative propagation, in vitro propagation of northern red oak (*Q rubra* L.) shoots was achieved from cotyledonary node explants excised from in vitro grown 8 week-old seedlings, with a yield of 20 shoots per cotyledonary node (Kovacset al, 2009). *Q robur* can be also asexually propagated using micropropagation by shoot cultures using materials from juvenile seedlings and stump sprouts of mature trees.

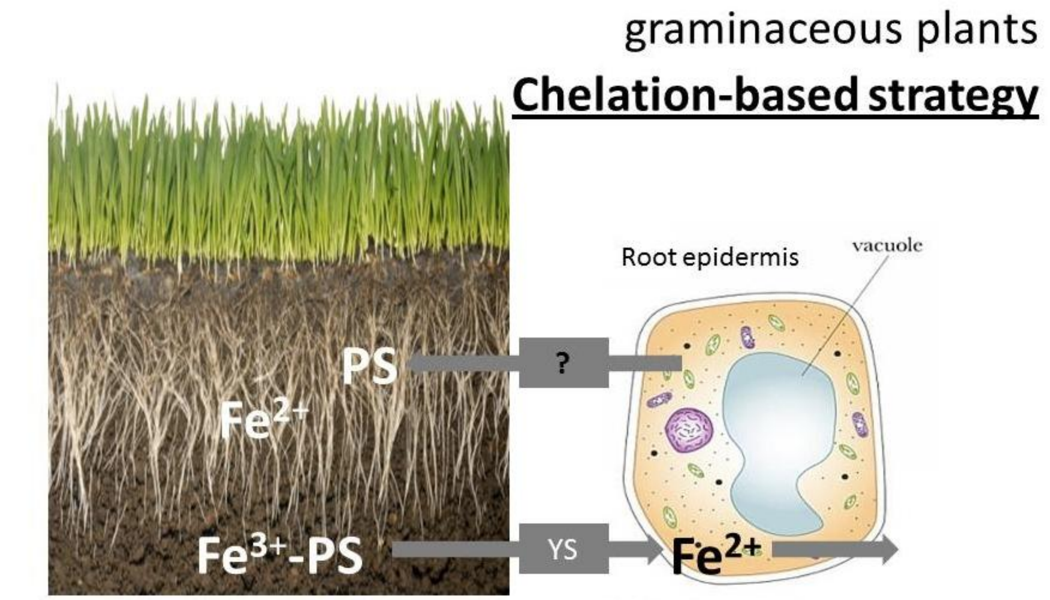
The research group led by Dr. Nina Bassuk at Cornell University developed a unique field layering method by successfully combine etiolation, rejuvenility, and plant growth hormone treatments, achieving a high rooting percentage in field layering propagation. New shoots arise from the base of cutback stock plants rooted very well after being etiolated and treated with high concentration of Indole-3-butyric acid dissolved in aqueous ethanol solution (Amissah, et al., 2007).

After vegetative propagation techniques have been developed, selecting hybrid oaks with preferable features such as environmental, disease and insect tolerance, special aesthetic value, or better growth will be possible.

Due to the intensive construction in urban areas, urban soils with pH over 7.5 can be a restriction to those plants sensitive to high pH. Many oaks native to the Northern US such as *Q bicolor,Q montana, and Q palustris* may become chlorotic and show poor growth in soil pH higher than 7.

The alkaline tolerance of plants depends on the plant's ability to take up nutrients that are less soluble at high pH. Essential nutrients such as iron, manganese, copper and zinc become significantly less available in high pH soil due to their lack of solubility even though they may be abundant in the rhiziosphere. Iron is particularly important among these elements since it plays an irreplaceable role in functional processes such as respiration, photosynthesis, DNA synthesis, nitrogen fixation, and hormone production. Plants with an iron deficiency develop the symptom of interveinal chlorosis on upper leaves, poor root formation and growth retardation. When this is severe, it may result in the death of plants. The symptoms of Fe deficiency are very commonly found in some plants in Quercus spp. and have become the biggest impediment to using some oaks in urban areas (Morrissey&Guerinot, 2009). Like other woody species such as Taxodium spp., most oaks with known tolerance to alkaline soils were naturally discovered in Mexico, south Texas and western states.

Romheld and Marschner (1986) first proposed two different mechanisms for iron uptake in plants under high pH condiions. These utilize two valence states of Fe ions in soil, Fe(II) and Fe(III), namely reduction-based strategy (strategy I) and chelation-based strategy (strategy II), in non-graminaceous plants (non-grasses) and graminaceous plants (grasses) respectively, shown as Figure 1 below.



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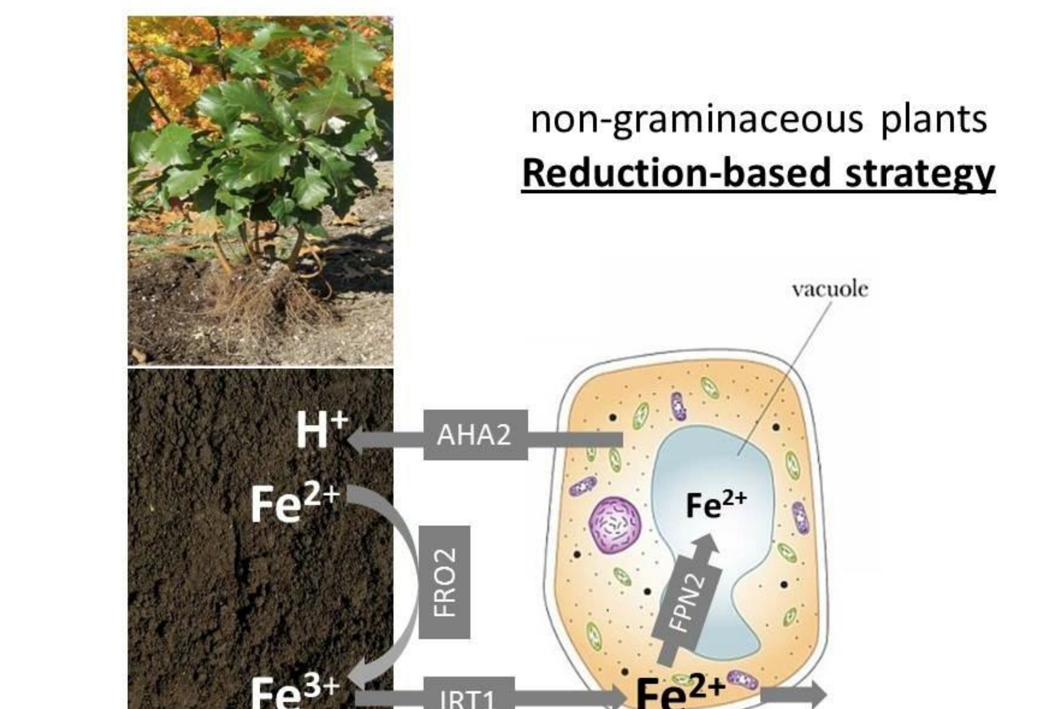

(Modified from Morrissey and Guerinot, 2009, Chem. Rev.)

Figure 1.Fe uptake from soil reduction strategy and chelation strategy.

In strategy I plants, Fe(III) is reduced to Fe(II) by ferric chelate reductase (FRO), which is then carried into the root epidermis by the iron-regulated transporter (IRT). FPN2, a divalent metal effluxer in the epidermis, sequesters free Fe ions and has them bound in the vacuole. Arabidopsis thaliana is the most commonly used model plant in research with this mechanism (Enomoto, et al., 2009).

Strategy II plants, including important agricultural crops (wheat, rice and maize) can release phytosiderophores (PSs), a group of chelators in their root zones that are able to chelate Fe(III) into Fe(III)-PS complex and have them carried into root membranes by members of YS/YSL family (YS1 in maize and barley, and OsYSL15 in rice).

Although the mechanism of iron uptake and deficiency of oaks has not been studied thoroughly, as far as it is known now, woody plants not sensitive to high pH should be able to reduce the insoluble Fe(III) into soluble Fe(II) which can be utilized in their metabolism. In conclusion, as an irreplaceable essential element, iron is highly correlated to chlorophyll content and the deficiency is also easy to be found. Accordingly, chlorophyll content is commonly used as an indicator to test the Fe supply and availability under high pH conditions.

The objective of this research is to propagate hybrid oak crosses between native oaks with good cold tolerance and oaks from many areas that may be tolerant of alkaline soil, using the method developed by Amissah, et al. in 2007, and select those plants with alkaline tolerance and winter hardiness, therefore producing trees better adapted to urban environments.

CHAPTER 2

MATERIALS AND METHODS

1. Plant materials

During 2004 and 2006, 8 species of the white oak group were used as maternal parents and crossed with pollen from 42 species found throughout the United States, Europe and Asia (Table 1). In the spring of 2008, 361 hybrid seedlings were planted in Arkport Sandy Loam at the Blue Grass Lane horticultural research area of Cornell University in Ithaca NY.

Table 1.List of plant materials with their original female and male pareents

Maternal Parent	Paternal Parent	Number of Genotypes
Quercus 'Ooti' *(Q mac x Q robur)*	*Quercus fusiformis*	1
Quercus bicolor	*Quercus robur argentomarginata*	1
	Quercus affinis	3
	Quercus aliena	13
	Quercus aliena acuteserrata	15
	Quercus austrina	4
	Quercus bebiana	5
	Quercus bicolor	8
	Quercus chapmanii	4
	Quercus dentata 'Carl Ferris'	3
	Quercus dentata pinnatifida	4
	Quercus fabri	14
	Quercus fruiticosa	4
	Quercus fusiformis	2
	Quercus gambelii	6
	Quercus geminata mix	2
	Quercus glauca	1
	Quercus graciliformis	11
	Quercus libani	3
	Quercus lyrata	2
	Quercus macranthera	1

Maternal Parent	Paternal Parent	Number of Genotypes
	Quercus mexican sp. Plant Delights	3
	Quercus minima	5
	Quercus mongolica grosserata	3
	Quercus muehlenbergii	22
	Quercus myrsinifolia	23
	Quercus phillyreoides	7
	Quercus polymorpha	4
	Quercus robur 'Pectinata'	9
	Quercus robur aureum	4
	Quercus rugosa	13
	Quercus spp.	5
	Quercus spinosa	2
	Quercus turbinella	8
	Quercus vaseyana	6
Quercus gambelii x macrocarpa	*Quercus lyrata*	2
	Quercus x comptoniae	2
Quercus macrocarpa	*Quercus gambelii*	6
	Quercus lyrata	1
	Quercus macroparpa	12
	Quercus prinoides	13
	Quercus turbinella	1
	Quercus undulata	4
	Quercus x comptoniae	1
Quercus macrocarpa 'Ashworth Strain'	*Quercus fusiformis*	2
	Quercus geminata mix	1
	Quercus lyrata	3
	Quercus michauxii	3
	Quercus minima	1
Quercus montana	*Quercus geminata mix*	2
	Quercus lyrata	1
Quercus muehlenbergii	*Quercus aliana acuteserrata*	1
	Quercus fusiformis	2
	Quercus geminata mix	16
	Quercus lyrata	2
	Quercus michauxii	3

Maternal Parent	Paternal Parent	Number of Genotypes
	Quercus muehlenbergii	3
	Quercus minima	3
	Quercus prinoides	4
	Quercus virginiana nc state	6
	Quercus virginiana Taylor's	4
	Quercus x comptoniae	3
Quercus x warei 'Long' REGAL PRINCE	*Quercus x comptoniae*	17
	Quercus x warei 'Long' REGAL PRINCE	8

2. Hybrid oak field-layering propagation

2.1 Pretreatment of stock plants

This study of hybrid oak propagation began in early May of 2009 using a modified version of the oak propagation protocol developed by Amissah et al. (2007). Before bud break, hybrid oak seedlings were cut back to stumps 10 cm high. About 2-3 weeks later, after buds had begun to swell around the stump, the plants were covered with No.2 containers (7.57 liter in volume) to create a shaded environment as the new shoots grew. The containers were wrapped with heavy-duty aluminum foil to reduce heat accumulation under the containers.

2.2 Field layering propagation in 2009

Figure 2.Hybrid oak field during etiolation process

Each pot was secured with a brick on the top (shown in Figure 2). As a result, etiolated shoots were produced under shade and grew to an average length of approximately 12cm in 7-10 days. At this point, shoots less than 5cm were removed. At this time, numbers of new shoots were recorded for the first time. The remaining shoots were sprayed with 8,000 ppm Indol-3-butyric Acid (IBA) dissolved in 98% of aqueous ethanol (v/v), on the basal 3cm of the new shoots. Stock plant shoots were allowed to dry for 10-15 min after the treatment, and then were covered by No.2 light bottomless pots. The pots, which had been wrapped with light reflective aluminum,were used to keep pre-moistened Promix[1] (a peat-based growing medium with vermiculite and perlite by Primer Horticulture, Inc.) around the treated shoot basis while leaving shoot tips out of the medium.

Figure 3.Cut back plant and etiolated new shoots (Left)

Figure 4.Treated shoot bases mounded with Promix (Middle)

Figure 5.White plastic top covered bottomless pot with shoots tips growing out (Right)

The bottomless pots were covered with white plastic over the open top to provide temporary shade. Two cuts were made on each plastic top to reduce humidity. Two weeks later, the white plastic tops were cut off as etiolated shoots gradually greened up and grew out of the bottomless pots. As the shoots grew, moist Promix was added, eventually filling the pots to top. Since many plants grew at different rates, all treatments were completed in late July of 2009.

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[1] Main components: Canadian Sphagnum Peat Moss (75-85 % / vol.), Perlite — horticultural grade, Vermiculite, Dolomitic & Calcitic Limestone (pH adjuster), Macronutrients, Micronutrients, Wetting Agent

Figure 6.Hybrid oaks in the field in summer of 2009

Any damage or death of shoots was recorded as it occurred. All plants grew in the field until November. The growing points of the shoots were removed throughout the summer in order to maintain shoot lengths of 60cm. Rooted shoots were detached from the stock plants and potted up into No.1 (3.78Liter) containers in early November of 2009. Numbers of rooted shoots were recorded during harvest. They were thoroughly watered before being moved into an unheated covered overwintering structure.

Figure 7.Rooted shoots in November 2009

Figure 8.Newly propagated hybrid oaks from one stock plant

2.3 Field layering propagation in 2010

Hybrid oak propagation was repeated in 2010. Due to the warmer weather, plants broke bud earlier and were cut back in April. All treatments were finished in June 2010. Most propagation procedures were identical to 2009 except for the following: IBA concentration was reduced from 8,000 to 6,000 ppm in 98% aqueous ethanol and applied by a soft paint brush to induce root formation while minimizing chemical toxicity, silver colored light reflective metal mesh trashcans (30 x 30 x 35cm) were used to cover the stock plants after initial etiolation, and IBA treatments. Bottomless pots were still used to hold the moist Promix around the treated layers. Mesh trashcans (Figure 9) were used in place of the white plastic. Shoots greened up under the shade for one week and trashcans were removed.

Figure 9. Weaning under a mesh trashcan

3. Alkaline tolerance evaluation in open field in 2010

3.1 Alkaline treatment

Newly propagated hybrid oak layers were transplanted into Arkport sandy loam soils of natural pH 6.5 or soil limed to pH 8.0 in late May 2010. Equal numbers of clones were assigned into the high and low pH soils. Plants were then allowed to grow until late July.

3.2 GA treatment for growth stimulation

A solution of 500ppm GA_3 ($C_{19}H_{22}O_6$) dissolved in 50% aqueous ethanol (v/v) was then applied to dormant buds every 5 days for one month to stimulate shoot growth.

Figure 10.Hybrid oak growth before and after applying GA_3

3.3 Chlorophyll rating

A SPAD chlorophyll meter (SPAD 502 from spectrum technologies, INC) was used to measure the optical density difference at two wavelengths in order to estimate the chlorophyll content. The SPAD meter rating on greenness of leaves was taken twice: at the beginning of leaf growth in early August and after all plant growth and budset in late September.

4. Alkaline tolerance evaluation

4.1 Hybrid oaks overwintering and handling

For the first year of this project, newly propagated oaks were detached from stock plants and potted up into PROMIX and moved into non-heated overwintering structure in late fall of 2010. In spring of 2011, hybrids were transplanted into arkport field soil of pH6.0 and pH8.0 respectively.

In late November of 2010, field planted shoots from 2009 and newly harvested rooted shoots from 2010 were all potted up into peat/perlite 50/50 v/v soilless mix adjusted to pH 8 and pH 6 and placed in a 5 C cooler for 3 months. Whiting Dolomitic Limestone (Whittemore Company, Inc., Lawrence, MA) was added to soilless mix, the amount of 0.593 kg/m^3 and 11.866 kg/m^3 were used to achieve the desire pH of 6.0 and 8.0.

Plants were taken out of the cooler in March 2011 and moved into a glass greenhouse, which was maintained a temperature between 15 C and 25 C. In order to ensure a 16 hours light period, HID lights were used as supplemental lighting. Control released fertilizer Osmocote with an N: P: K ratio of 15:9:12 and MICROMAX by Scotts were applied in early April to provide nutrients.

4.2 Chlorophyll rating

In purpose of testing the ability of hybrids to survive in alkaline soil, the greenness of leaves is the most commonly tested parameter, since Fe is one of the key components of chlorophyll. The SPAD meter[2] using differential transmission at two wavelengths, 940 and 665 nm, to

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[2]SPAD Meter, Minolta SPAD 502®

determinethe absorbance of chlorophyll pigments (Richardson, et al., 2006). In this study, with sufficient macronutrients and micronutrients provided, hybrid oaks with higher rating of greenness were considered to tolerate soils of high alkalinity. When taking SPAD reading, the second layers of leaves from the apex, which were fully matured, were used as sample leaves as Fe is not phloem mobile and can not relocate from lower leaves to upper ones.

4.3 Alkaline tolerance evaluation

Hybrid oaks transplanted into field soils were evaluated in August and October of 2010 for twice. SPAD meter was used to take the top layer of fully expanded leaves avoiding any mid vein and juvenile leaves with different colors. Six readings of SPAD were taken on each plant to insure the accuracy. Due to the growth redundant after transplant shock, SPAD data were taken again in October when all leaves stopped growing and provided a mature color.

In spring of 2011, alkaline tolerance evaluation was done in greenhouse instead of open field in order to get better control of environmental conditions. SPAD data were also taken twice since the two groups of hybrid oaks propagated in in 2010 and 2009 had different rate of growth. Six readings were recorded on each plant. Data taken on plants propagated from same stock plants were analyzed in together.

5. Statistical Methods

The statistical software of JMP 8.0 produced by SAS Institute Inc. was used to analyze all the data. Specifically, Analysis of Variance, Matched Pairs and Tukey's pair wise comparison were used.

CHAPTER 3

RESUILTS AND DISCUSSIONS

1. Shoots produced by cutback stock plants.

Shoot number is one of factors that greatly impact the efficiency of layering propagation, since bigger numbers of shoots give more opportunities to form adventitious root on one stock plant.

1.1 Shoots in different years or seasons

Number of shoots produced by cutback stock plants differs in propagation year 2009 and 2010. The mean number of shoots produced in 2009 was 6.3, which is significantly higher than the mean of 4.2 in 2010. After two times of severely cutting back the stock plants, stored carbon accumulated in the past few years may have been consumed during the propagation, which may caused the decreased amount of shoots produced.

Table 2.Mean number of shoots produced by each stock plant

Year/Season	Number of Shoots Produced by Each Stock Plant
2009	6.25
2010	4.15

Number of shoots produced per stock plant in 2009 was significantly greater ($p<0.0001$) than it was in 2010.

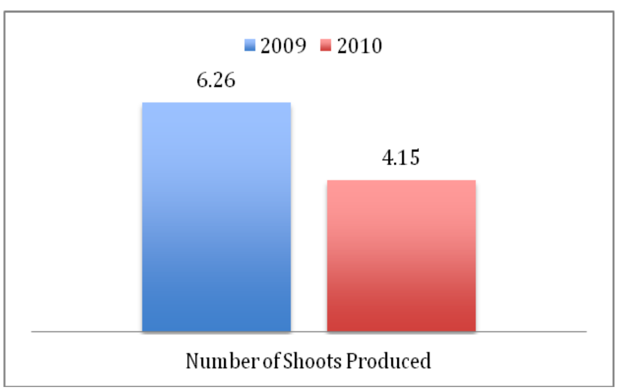

Figure 11.Mean number of shoots produced by each stock plant

Because of the changes in the layering propagation made in IBA concentration and weaning methods in 2010s, the loss of shoots produced by stock plants significantly decreased during 2010. As a result, although the shoots numbers produced in 2010 were lower than 2009, the effective numbers of shoots participating the rooting process (the original number of shoots produced in spring minus the number of shoots lost during the etiolation and hormone treatments) proved to be similar to the number in 2009.

There were also differences among the number of shoots produced by the cut-back stock plants created in 2004, 2005 and 2006, however, they did not make a difference with the effective number of shoots participating in rooting. The table below shows the number of shoots produced in spring from plants created in three successive years. The numbers were statistically different before stock plants pretreatments, but became similar (with a p-value of 0.88) before the rooting process. Therefore, the year that the hybrid was created did not influence the number of shoots produced.

Table 3.Number of shoots produced and shoots participating in adventitious root formation

Year	Number of Stock Plants	Mean of Shoots Produced	Mean of Shoots Survived Before Rooting
2004	53	9.36	6.75
2005	37	12.78	6.91
2006	152	10.20	7.03

The numbers of shoots produced in spring of stock plants vary among hybrids.

1.2 Shoots produced by different stock plants

Numbers of shoots produced are significantly different among stock plants' female parents, but not significant among male parents. Pair wise, *Quercus muehlenbergii* has the most shoots produced of 12.8 shoots per plant as a hybrid female parent, which is significantly different from *Quercus bicolor* of 9.7, the one with least number of shoots produced. All the remaining three matrenal parents have not shown any differencesin their ability to produce new shoots. *Quercus xwarei* ‘Long’ REGAL PRINCE produced a mean of 12 shoots per stock plant； *Quercus macrocarpa* ‘Ashworth Strain’ had a mean of 10.8 shoots per stock plants; Stock plants had *Quercus macrocarpa* as female parent had a mean of 10.5 shoots per plants.

Table 4.Shoot number of stock plants produced by hybrid female parent

Female Parent	Mean of Shoots Produced	Number of Hybrids
Quercus muehlenbergii	12.8 a	32
Quercus xwarei 'Long' REGAL PRINCE	12.0 a b	25
Quercus macrocarpa 'Ashworth Strain'	10.8 a b	6
Quercus macrocarpa	10.5 a b	17
Quercus bicolor	9.7 b	175

Table 5. Analysis of variance of shoot number of stock plants produced by hybrid female parent

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Female Parent	4	330.7713	82.6928	3.9694	0.0039*
Error	240	4999.8247	20.8326		
C. Total	244	5330.5959			

Since the number of shoots produced determined the potential number of clonal plants, stimulating more bud break, shoot growth, and preserving shoot number and quality during propagation greatly affected the number of new plants produced by the stock plants. Maximizing bud break potential by plant regulators such as GA_3 can be a solution, which may have positive influence on overcoming the depression after transplant, or any seasonal issue that may cause the slow bud break or shoot growth.

2. Survival of shoots produced by stock plants before root formation

2.1 Optimized IBA concentration

A significant proportion of shoot loss was observed during 2009 after application of the Indol-3-butyric Acid and the weaning process from etiolation to full sun. There was an average loss of 43% of shoots produced in spring before the layering propagation began, which considerably decreased the propagation rate in 2009. After a modification of the weaning technique and reduced IBA concentration, the average loss rate effectively decreased to 17%.

2.2 Improved weaning technique

Table 6. Percentage shoot loss during stock plant pretreatment before root formation

	Shoot Loss % (Mean ± SD)standard deviation
2009	42.9 ± 26.0
2010	17.2 ± 27.9

As the most serious problem occurred in the year of 2009, the damage on the shoot tips in the weaning procedure after etiolation was mostly caused by lacking of air movement in the closed bottomless pots with white plastic. The cuts made through the white plastic topdid not allow enough air to go through and that led to moisture building up and fungal problem, which damaged many shoot tips. After the fungal infection, those shoots were burned by sunlight in very hot July and result in further damage. In 2010, silver painted mesh trashcans providing part shade and allowing air movement around the very brittle shoots substituted the bottomless pots with white plastic top, and performed very well in reducing shoot loss. Accordingly, the concentration of IBA solution used to stimulate root formation was decreased from 8,000 ppm in 2009 to 6,000 ppm in 2010 to reduce the toxicity to plant tissue.

3. Rooting percentage of stock plants

3.1 Rooting percentage produced by different stock plants

Rooting percentages of field-container layering propagation were different among female parents of stock plants. In the comparison of means of rooting percentage among female parents, Quercus xwarei 'Long' REGAL PRINCE and Quercus macrocarpa had rooting percentages of 53% and 49%, which are significantly higher than Quercus bicolor of 20.1%, Quercus macrocarpa 'Ashworth Strain' of 17.2% and Quercus muehlenbergii of 5%. The lowest Quercus muehlenbergii was significantly lower than all the others except Quercus macrocarpa 'Ashworth Strain'.

Table 7. Rooting percentage of shoots produced by stock plants

Maternal Parent	Mean of Rooting Percentage	Number of Hybrids
Quercus x warei 'Long' REGAL PRINCE	53.0% a	25
Quercus macrocarpa	49.0% a	16
Quercus bicolor	20.1% b	163
Quercus macrocarpa 'Ashworth Strain'	17.2% b c	6
Quercus muehlenbergii	5.0 % c	32

Table 8. Analysis of variance on rooting percentage of shoots produced by stock plants

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Female Parent	4	4.527043	1.13176	19.4468	<.0001*
Error	237	13.792855	0.05820		
C. Total	241	18.319898			

Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.74890	0.05

Table 9. Pair wise comparison by Tukey's method on rooting percentage of shoots produced

Level			Mean
Quercus xwarei 'Long' REGAL PRINCE	A		0.53029986
Quercus macrocarpa	A		0.49003294
Quercus bicolor	B		0.20074645
Quercus macrocarpa 'Ashworth Strain'	B	C	0.17222222
Quercus muehlenbergii		C	0.05026042

3.2 Modified propagation technique and improved rooting percentage.

After a year of propagation, the field layering technique was modified to reduce the shoot loses experienced in 2009. IBA concentration may have been one of the key factors that damaged the etiolated shoots before the rooting process began; very moist, plastic topped bottomless pots also caused fungal growth on the developing shoots contributing to low rooting percentages. After tested in the greenhouse on other oak species, 8,000ppm IBA was proven to be super-optimal since two thirds of shoots had severe damage. However, 6,000ppm, applied to the basis of etiolated shoots as control group had minor injury on the brittle shoots.

Figure 12.Etiolated shoots damage by super-optimal concentration of IBA

(Shoots marked with red tape was treated by 8,000ppm IBA, the control was 6,000ppm)

Table 10. Shoot damage statistics after IBA treatments

	8,000 ppm IBA	6,000 ppm IBA
Healthy shoots %	29%	74%
Damaged shoots %	71%	26%

3.3 Possible changes for future testing

Modifying the weaning approach and reducing IBA concentration did reduced the death rate of shoots prior to root formation quite a bit. However, the etiolated shoots under silver colored mesh trashcan greened up so easily and quickly that they might not have enough time period to take advantage of the etiolation and develop root primordial. As a result, the weaning method did help to make shoots strong enough to overcome any environmental or physiological stress during the rooting process yet did not improve the rooting percentage significantly. In this case, 6,000ppm IBA, as it has been tested by Amissah et al. in 2007, might not be effective enough to stimulate rooting. From the experience gained in 2009 and 2010, 8,000ppm IBA may still be used and combined with the mesh trashcan's weaning procedure to maximize the rootability.

4. Powdery Mildew Infection by maternal parents of stock plants

In 2009, the percentage of plants infected by powdery mildew was 21.8%, which was significantly higher than of 9.9% in 2010. The improvement in 2010 also suggested the modified weaning method reduced the moisture in pots and decreased the chances of being infected by mildew. When considering the two years together, the relationship between the likelihood of infected by powdery mildew and the female parent of the stock plant is shown in the Table11.

Table 11. Possibilities of powdery mildew infection by female parent of stock plants

Female Parents	Number of Hybrid	Mean Possibility of Infected Mildew (mean ± SE) (%)
Quercus x warei 'Long' REGAL PRINCE	25	72% ± 11
Quercus macrocarpa 'Ashworth Strain'	6	50% ± 22
Quercus muehlenbergii	32	34% ± 10
Quercus macrocarpa	17	29% ± 13
Quercus bicolor	163	25% ± 4

Among the five female parents, *Quercus xwarei* ‘Long’ REGAL PRINCE had the highest rate of infection by powdery mildew. As a hybrid cultivar itself, the *Quercus xwarei* is a commercial cross between *Quercus robur* 'Fastigiata' and *Quercus bicolor*. *Quercus robur*is very susceptive to powdery mildew, which may have led to this result.

5. Alkaline tolerance evaluation of hybrid oaks

5.1 Growth of hybrids under high pH condition

Newly propagated hybrid oak trees did not have much growth by July of 2010. The buds did not grow and very few plants had expanded leaves. After GA had been applied, most plants had a first flush of growth in terms of leave expansion; however, significant shoot growth was not observed especially with the group in high pH soils.

Consequently, those hybrids were potted up into peat and perlite 1:1 (v/v) with pH adjusted to 6 and 8 correspondingly and moved into a cooler with the other group of hybrids just propagated in fall of 2010 in order to get better controlled environment condition than the field.

In the spring of 2011, after 4 months at 5 degrees Centigrade, hybrid oaks were moved out from cooler and kept in a greenhouse. They grew very vigorously without any plant regulator. The group propagated in 2010 was again relatively slow yet had their top leaves fully expanded by the end of May. Some small plants died before bud break, however, the proportion was lower than 2010 when plants were planted in the field.

pH 8.0 (Left) pH 6.0 (Right)

Figure 13. Growth of hybrid oaks propagated in 2010 in greenhousein June 2011

pH 8.0 (Left) pH 6.0 (Right)

Figure 14. Growth of hybrid oaks propagated in 2009 in greenhouse in June 2011

__5.2 Chlorophyll rating of hybrids under high pH condition__

To evaluate the tolerance of hybrids, we measured the greenness rating of hybridsusing the SPAD meter.

After the growth stimulation in summer of 2010, SPAD meter readings were taken to determine their performance in both acid and alkaline soils of fully expanded leaves. They were some distinctive symptom of interveinal chlorosis found on plants in alkaline soil, while some individuals were still healthily grown in the same soil.

Figure 15. Healthy green leaves (left) and chlorotic leaves (right) in alkaline soils

Unfortunately, due to the small numbers and uneven growth of new hybrids in alkaline and acid soils, further test are needed to achieve consistent results.

In May of 2011, SPAD meter readings were taken from hybrid oaks propagated in 2009 and 2010. It showed that the chlorophyll rating of plants in pH 8.0 treatments was significantly lower than in pH 6.0 treatments. The mean SPAD rating for pH 8.0 oaks were 2.55 lower than the pH 6.0 group. The results showed the same trend with the group of hybrids propagated in 2010. The mean difference between plants in alkaline soil and acid soil was 5.03.

Figure 16. Chlorotic leaves and their SPAD reading

Lower left:	extreme chlorotic;	SPAD<5
Upper left:	very chlorotic;	SPAD=5-15
Upper right:	somewhat chlorotic;	SPAD=15-25
Lower right:	healthy and green;	SPAD>25

Table 12. Hybrid propagated in 2011 with potential alkaline tolerance.

Plant Code	Female Parent	Male Parent	May SPAD	June SPAD	May SPAD	June SPAD
	1-year-old plants		*High pH*		*Low pH*	
04-560-5	*Quercus bicolor*	*Quercus bicolor*	27.5	**34.8**	29.2	**33.4**
06-1813-3	*Quercus bicolor*	*Quercus rugosa*	22.4	**28.8**	25.3	**25.7**
06-1747-1	*Quercus bicolor*	*Quercus robur 'Pectinata'*	24.1	**33.1**	24.1	**36.2**
06-1819-1	*Quercus gambelii x macrocarpa*	*Quercus lyrata*	29.7	**29.2**	30.6	**30.3**
04-576-3	*Quercus macrocarpa*	*Quercus gambelii*	26.5	**30.5**	31.4	**32.9**
06-1673-8	*Quercus macrocarpa*	*Quercus macrocarpa*	29.9	**40.7**	33.7	**42.4**
05-906-3	*Quercus macrocarpa 'Ashworth Strain'*	*Quercus minima*	33.8	**36.5**	42.6	**39.3**
05-805-1	*Quercus montana*	*Quercus geminata mix*	22.2	**30.6**	37.8	**32.9**
06-1800-13	*Quercus x warei 'Long'* REGAL PRINCE	*Quercus x comptoniae*	33.1	**37.2**	35	**37.2**

Table 13. Hybrid propagated in 2011 with weak potential alkaline tolerance.

Plant Code	Female Parent	Male Parent	May SPAD	June SPAD	May SPAD	June SPAD
	1-year-old plants		*High pH*		*Low pH*	
04-560-3	*Quercus bicolor*	*Quercus bicolor*	28.7	**29.1**	35	**37**
06-1730-1	*Quercus bicolor*	*Quercus bicolor*	N/A	**14.8**	31.6	**32.1**
06-1720-7	*Quercus bicolor*	*Quercus phillyreoides*	20.4	**16.9**	24.6	**29.5**
06-1500-6	*Quercus x warei* 'Long' REGAL PRINCE	*Quercus x warei* 'Long' REGAL PRINCE	29.4	**28.5**	26.2	**34.3**

Table 14. Hybrid propagated in 2010 with potential alkaline tolerance.

Plant Code	Female Parent	Male Parent	May SPAD	June SPAD	May SPAD	June SPAD
	2-year-old plants		*High pH*		*Low pH*	
04-561-1	*Quercus bicolor*	*Quercus bebiana*	30.4	**29.3**	35.45	**28.85**
04-566-3	*Quercus bicolor*	*Quercus muehlenbergii*	34.05	**32.95**	32.9	**33.8**
05-830-50	*Quercus bicolor*	*Quercus rugosa*	30.85	**30.1**	28.2	**26.7**
06-1633-1	*Quercus bicolor*	*Quercus vaseyana*	30.5	**28.3**	34.2	**27.8**
06-1733-17	*Quercus bicolor*	*Quercus aliena acuteserrata*	42.4	**44.5**	40.2	**39.4**
06-1742-1	*Quercus bicolor*	*Quercus fruticosa*	34.8	**39.5**	35.7	**27.9**
04-576-1	*Quercus macrocarpa*	*Quercus gambelii*	35.5	**41.4**	35.1	**39.75**
04-576-3	*Quercus macrocarpa*	*Quercus gambelii*	34.55	**35.25**	34.3	**37.1**
06-1800-13	*Quercus x warei* 'Long' REGAL PRINCE	*Quercus x comptoniae*	33	**37.4**	37.7	**40.8**

Table 15. Hybrid propagated in 2010 with weak potential alkaline tolerance.

Plant Code	Female Parent	Male Parent	May SPAD	June SPAD	May SPAD	June SPAD
	2-year-old plants		*High pH*		*Low pH*	
04-567-2	*Quercus bicolor*	*Quercus mexican sp. Plant Delights*	34	**9.8**	36.3	**31.8**
06-1633-1	*Quercus bicolor*	*Quercus vaseyana*	30.8	**4.9**	28.2	**26.7**
06-1811-3	*Quercus bicolor*	*Quercus fabri*	36.3	**18.5**	31.1	**37.8**
06-1673-4	*Quercus macrocarpa*	*Quercus macrocarpa*	37.5	**16.8**	37.9	**37.6**

In general, the alkaline tolerance evaluation, which was done in the greenhouse in 2011, was much more successful than the previous year in the field. Because of transplant shock, the growth of one-year-old hybrids propagated in 2011 was less than the two-year-old group. However, greenhouse –grown plants showed better growth, and the SPAD rating was quite different among treatment groups. The Table 12, 13, 14, and 15 listed the SPAD data taken from the hybrids in May and June. Since some plants did not have fully expanded leaves in May, the June data is the major set to be analyzed in terms of the alkaline tolerance in the growing season of 2011. Each row represents a hybrid stock plant with their original female and male parent's name, the number of individuals in high pH and low pH groups vary, but the plants were completely identical to each other since they were asexually propagated from one plant. Plants with equal or even higher SPAD numbers in high low small numbers in high pH soil all have the chlorotic symptom as shown in Figure 16. Lower number indicates worse alkaline tolerance. Plants with leaves in pale yellow were very likely to die in alkaline environment. When looking at the parents of plants with potential alkaline tolerance, species such as *Q gambelii, Q macrocarpa, Q rugosa* etc. were commonly found as male parents, which may be the source of where the hybrids got the abilities to grow well and take up iron in alkaline soil. Meanwhile, some plants with female or male parent known to tolerate alkaline soil showed poor growth and became chlorotic in high pH were also observed. There was one special plant crossed by *Q bicolor and Q vaseyana* that produced both alkaline tolerant clones and alkaline sensitive clones. In theory, plants cloned from one stock plant should have same potential of alkaline tolerance. However, environmental stress, such as temperature extremes, drought, poor drainage (which limits soil aeration) or restricted root growth in container, would limit nutrient uptake in plants that may be sensitive to soil pH and nutrient availability.

6. Conclusions

This study, starting from spring of 2009 to spring of 2011, showed that the field layering propagation protocol developed by Amissah et al, that was effective on several species of oaks such as *Quercus macrocarpa*, *Quercus bicolor* and *Quercus robur* was effective on a wide range of hybrid oaks in the white oak group. Progress was made on increasing the new shoot survival rate and improving the technique associated with etiolation approaches and auxin-aid rooting process. This series of asexual propagation method has also been tested on *Chionanthos virginicus* and *Juglans ailantiforlia* and was successful. Therefore, this method would be expanded to other hard-to-root species.

The study went through a procedure of selecting hybrid parents for offspring with desirable physiological features. The key to this procedure is to select parents that have the capability to produce clones by asexual means in order to produce hybrids with desirable characteristics.

From the alkaline tolerance evaluation, hybrids between native species with winter hardiness and non-native species known to have tolerance to alkaline soil did produce individuals with ideal alkaline tolerance and can be used for urban area with soils in high pH. The newly propagated hybrids could be grown in both open field and greenhouse, however, performed much better in terms of growth rate and vigor in a controlled environment.

7. Further Testing

Since the hybrids propagated in 2009 showed tremendous growth, and provide very distinctive results on SPAD reading, it is proved that 2^{nd} year of growth is needed for new hybrids in order to be evaluated. The group propagated in 2010 had limited growth; continue evaluation needed to be done next year to select consistent genotypes for alkaline tolerance. Moreover, the results would more reliable if the hybrids could have depleted any nutrients they may have stored from the stock plants in the following years.

APPENDIX

Table 16. Original data of layering propagation of hybrid oaks in 2009 and 2010

Tree ID	Female Parent	Male Parent	Year	Hybrid Code	09 Shoots	09 Dead	09 Rooted	09 Mildew	10 Shoots	10 Dead	10 Rooted	10 Mildew
06-1725-1	Quercus bicolor	Quercus affinis	2006	142	5	1	0	0	3	0	1	0
06-1725-2	Quercus bicolor	Quercus affinis	2006	142	4	2	0	0	2	0	0	0
06-1725-4	Quercus bicolor	Quercus affinis	2006	142	4	1	0	1	4	1	0	0
05-853-1	Quercus muehlenbergii	Quercus aliana acuteserrata	2005	641	12	7	2	0	15	0	1	0
05-853-3	Quercus muehlenbergii	Quercus aliana acuteserrata	2005	641	22	20	0	0	6	2	0	0
04-562-1	Quercus bicolor	Quercus aliena	2004	140	7	2	0	0	9	0	0	0
04-562-1-2	Quercus bicolor	Quercus aliena	2004	140	5	4	0	0				
04-562-1-3	Quercus bicolor	Quercus aliena	2004	140	2	2	0	0				
04-562-2	Quercus bicolor	Quercus aliena	2004	140	11	7	0	0	8	0	1	0
04-562-3	Quercus bicolor	Quercus aliena	2004	140	5	3	0	0	6	2	0	0
04-562-3-2	Quercus bicolor	Quercus aliena	2004	140	4	1	0	0				
04-562-3-3	Quercus bicolor	Quercus aliena	2004	140	4	2	0	0				
04-562-4	Quercus bicolor	Quercus aliena	2004	140	4	0	4	0	3	0	1	0
06-1724-1	Quercus bicolor	Quercus aliena	2006	140	5	1	0	1	2	0	0	0
06-1724-2	Quercus bicolor	Quercus aliena	2006	140	5	2	0	0	2	0	1	0
06-1724-3	Quercus bicolor	Quercus aliena	2006	140	4	2	0	0	2	0	0	0
06-1733-1	Quercus bicolor	Quercus aliena acuteserrata	2006	139	8	4	0	1	3	1	0	0
06-1733-10	Quercus bicolor	Quercus aliena acuteserrata	2006	139	2	2	0	0				
06-1733-11	Quercus bicolor	Quercus aliena acuteserrata	2006	139	4	1	0	0	5	2	1	0
06-1733-12	Quercus bicolor	Quercus aliena acuteserrata	2006	139	5	2	0	0	4	0	0	0
06-1733-13	Quercus bicolor	Quercus aliena acuteserrata	2006	139	6	4	1	1				

Tree ID	Female Parent	Male Parent	Year	Hybrid Code	09 Shoots	09 Dead	09 Rooted	09 Mildew	10 Shoots	10 Dead	10 Rooted	10 Mildew
06-1733-16	Quercus bicolor	Quercus aliena acuteserrata	2006	139	3	1	0	0	1	0	0	0
06-1733-17	Quercus bicolor	Quercus aliena acuteserrata	2006	139	6	3	3	0	2	0	0	1
06-1733-2	Quercus bicolor	Quercus aliena acuteserrata	2006	139	8	2	0	0	7	0	0	0
06-1733-3	Quercus bicolor	Quercus aliena acuteserrata	2006	139	3	2	0	0	4	0	1	1
06-1733-4	Quercus bicolor	Quercus aliena acuteserrata	2006	139	3	0	1	0	3	2	0	0
06-1733-5	Quercus bicolor	Quercus aliena acuteserrata	2006	139	5	2	0	0	2	2	0	0
06-1733-6	Quercus bicolor	Quercus aliena acuteserrata	2006	139	3	0	0	0	5	0	1	0
06-1733-7	Quercus bicolor	Quercus aliena acuteserrata	2006	139	5	3	0	0	1	0	0	0
06-1733-8	Quercus bicolor	Quercus aliena acuteserrata	2006	139	7	2	0	0	6	0	0	0
06-1808-1	Quercus bicolor	Quercus aliena acuteserrata	2006	139	5	1	0	1	4	1	0	1
06-1728-1	Quercus bicolor	Quercus austrina	2006	138	2	1	0	0	2	1	1	0
06-1728-2	Quercus bicolor	Quercus austrina	2006	138	5	1	2	0	4	0	0	0
06-1728-3	Quercus bicolor	Quercus austrina	2006	138	2	0	0	0	4	0	0	1
06-1728-4	Quercus bicolor	Quercus austrina	2006	138	5	2	0	0	2	1	0	0
04-561-1	Quercus bicolor	Quercus bebiana	2004	137	10	4	5	0	4	0	0	0
04-561-2	Quercus bicolor	Quercus bebiana	2004	137	4	2	0	1	6	1	1	0
04-561-2-1	Quercus bicolor	Quercus bebiana	2004	137	5	5	0	0				
04-561-2-2	Quercus bicolor	Quercus bebiana	2004	137	6	3	0	0				
04-561-2-3	Quercus bicolor	Quercus bebiana	2004	137								
04-560-1	Quercus bicolor	Quercus bicolor	2004	111	11	7	0	0	1	0	0	0
04-560-2	Quercus bicolor	Quercus bicolor	2004	111	9	7	1	1	4	0	0	0
04-560-3	Quercus bicolor	Quercus bicolor	2004	111	10	0	7	0	11	1	2	0
04-560-5	Quercus bicolor	Quercus bicolor	2004	111	8	3	1	0	7	1	1	0
04-560-5-1	Quercus bicolor	Quercus bicolor	2004	111	6	1	0	0	2	0	0	0

Tree ID	Female Parent	Male Parent	Year	Hybrid Code	09 Shoots	09 Dead	09 Rooted	09 Mildew	10 Shoots	10 Dead	10 Rooted	10 Mildew
04-560-5-3	Quercus bicolor	Quercus bicolor	2004	111	4	3	0	0				
04-560-5-4	Quercus bicolor	Quercus bicolor	2004	111	2	1	1	0	1	0	0	0
06-1724-4	Quercus bicolor	Quercus chapmanii	2006	136	3	2	0	1	2	0	0	0
06-1727-1	Quercus bicolor	Quercus chapmanii	2006	136	8	0	1	0	8			
06-1727-2	Quercus bicolor	Quercus chapmanii	2006	136	8	5	1	0	5	1	0	1
06-1727-4	Quercus bicolor	Quercus chapmanii	2006	136	7	3	1	0	1	0	0	0
06-1805-1	Quercus bicolor	Quercus chapmanii	2006	136	4	0	0	0	4	0	0	0
04-570-1	Quercus bicolor	Quercus dentata 'Carl Ferris Miller'	2004	135	3	1	0	0	3	3	0	0
04-570-2	Quercus bicolor	Quercus dentata 'Carl Ferris Miller'	2004	135	0	0	0	0	3	1	0	0
06-1740-1	Quercus bicolor	Quercus dentata pinnatifida	2006	134	13	8	0	0	2	0	1	0
06-1740-2	Quercus bicolor	Quercus dentata pinnatifida	2006	134	4	0	0	0	1	0	0	1
06-1810-1	Quercus bicolor	Quercus dentata pinnatifida	2006	134	5	1	1	0	4	0	0	1
06-1810-2	Quercus bicolor	Quercus dentata pinnatifida	2006	134	16	4	11	1	7	1	0	0
06-1642-1	Quercus bicolor	Quercus fabri	2006	133	5	2	0	0	6	0	1	1
06-1741-1	Quercus bicolor	Quercus fabri	2006	133	5	1	1	0	4	0	1	1
06-1741-2	Quercus bicolor	Quercus fabri	2006	133	4	1	1	1	3	3	0	1
06-1741-3	Quercus bicolor	Quercus fabri	2006	133	3	3	0	0	4	0	1	0
06-1741-4	Quercus bicolor	Quercus fabri	2006	133	4	0	0	0	1	0	0	0
06-1741-5	Quercus bicolor	Quercus fabri	2006	133	4	3	0	0				
06-1741-6	Quercus bicolor	Quercus fabri	2006	133	6	4	1	0	2	1	0	0
06-1741-7	Quercus bicolor	Quercus fabri	2006	133	6	1	0	0	4	0	0	1
06-1741-8	Quercus bicolor	Quercus fabri	2006	133	5	1	1	0				
06-1811-1	Quercus bicolor	Quercus fabri	2006	133	10	6	0	0	8	1	0	0
06-1811-3	Quercus bicolor	Quercus fabri	2006	133	8	1	5	0	5	0	1	0
06-1811-4	Quercus bicolor	Quercus fabri	2006	133	6	4	0	0	3	1	2	0

Tree ID	Female Parent	Male Parent	Year	Hybrid Code	09 Shoots	09 Dead	09 Rooted	09 Mildew	10 Shoots	10 Dead	10 Rooted	10 Mildew
06-1811-5	Quercus bicolor	Quercus fabri	2006	133	7	5	0	0	4	0	0	0
06-1811-6	Quercus bicolor	Quercus fabri	2006	133	4	0	0	0	3	3	1	0
06-1742-1	Quercus bicolor	Quercus fruticosa	2006	132	5	2	3	0	2	0	0	1
06-1742-2	Quercus bicolor	Quercus fruticosa	2006	132	7	1	2	0	2	0	0	0
06-1812-1	Quercus bicolor	Quercus fruticosa	2006	132	6	0	1	0	4	0	0	0
06-1812-2	Quercus bicolor	Quercus fruticosa	2006	132	5	2	2	0	2	1	0	0
05-854-1	Quercus muehlenbergii	Quercus fusiformis	2005	831	8	5	0	0	9	6	0	0
05-854-10	Quercus muehlenbergii	Quercus fusiformis	2005	131	6	1	0	1	4	0	0	1
05-854-11	Quercus muehlenbergii	Quercus fusiformis	2005	131	5	3	0	0				
05-854-14	Quercus muehlenbergii	Quercus fusiformis	2005	431	4	2	0	0	9	0	0	1
05-854-15	Quercus muehlenbergii	Quercus fusiformis	2005	431	4	2	0	0	4	2	1	0
05-854-18	Quercus muehlenbergii	Quercus fusiformis	2005	631	15	13	0	0	7	6	0	1
05-854-19	Quercus muehlenbergii	Quercus fusiformis	2005	631	4	2	0	0				
05-854-2	Quercus muehlenbergii	Quercus fusiformis	2005	631	9	2	4	0	4	1	0	0
05-854-21	Quercus muehlenbergii	Quercus fusiformis	2005	631	4	2	0	0	6	4	0	0
05-854-22	Quercus muehlenbergii	Quercus fusiformis	2005	631	13	7	0	0	9	0	0	0
05-854-23	Quercus muehlenbergii	Quercus fusiformis	2005	631	7	4	0	0	4	3	1	1
05-854-5	Quercus muehlenbergii	Quercus fusiformis	2005	631	21	8	0	0	8	5	0	0
05-854-50	Quercus muehlenbergii	Quercus fusiformis	2005	631								
05-854-6	Quercus muehlenbergii	Quercus fusiformis	2005	631					5	1	0	0
05-854-7	Quercus muehlenbergii	Quercus fusiformis	2005	631	6	5	0	0	6	0	0	0
05-854-8	Quercus muehlenbergii	Quercus fusiformis	2005	631	5	0	0	0	5	0	0	0
05-872-1	Quercus muehlenbergii	Quercus fusiformis	2005	631	14	6	0	0	6	0	0	0
05-872-1	Quercus muehlenbergii	Quercus fusiformis	2005	631	5	3	0	0				
05-899-1	Quercus macrocarpa 'Ashworth Strain'	Quercus fusiformis	2005	631	4	3	0	0	3	0	2	0
05-899-2	Quercus macrocarpa 'Ashworth Strain'	Quercus fusiformis	2005	631	17	12	0	0	9	2	0	0
06-1816-1	Quercus bicolor	Quercus fusiformis	2006	631	4	3	1	0	5	1	0	0

Tree ID	Female Parent	Male Parent	Year	Hybrid Code	09 Shoots	09 Dead	09 Rooted	09 Mildew	10 Shoots	10 Dead	10 Rooted	10 Mildew
06-1816-2	Quercus bicolor	Quercus fusiformis	2006	631	8	0	1	1	7	0	0	1
05-922-1	Quercus 'Ooti'	Quercus fusiformis	2005	631	13	3	7	0	6	3	3	0
04-576-1	Quercus macrocarpa	Quercus gambelii	2004	330	8	2	6	0	4	0	3	1
04-576-1-1	Quercus macrocarpa	Quercus gambelii	2004	330								
04-576-3	Quercus macrocarpa	Quercus gambelii	2004	330	7	3	4	0	8	0	5	0
04-576-3-1	Quercus macrocarpa	Quercus gambelii	2004	330	4	3	0	0				
04-576-3-2	Quercus macrocarpa	Quercus gambelii	2004	330	3	1	0	0				
04-576-3-3	Quercus macrocarpa	Quercus gambelii	2004	330								
04-563-1	Quercus bicolor	Quercus gambelii	2004	130	7	1	1	0	8	1	0	0
04-563-1-1	Quercus bicolor	Quercus gambelii	2004	130	5	4	0	0				
04-563-1-3	Quercus bicolor	Quercus gambelii	2004	130	6	3	0	0				
04-563-1-4	Quercus bicolor	Quercus gambelii	2004	130	5	1	0	0	1	0	0	0
04-563-2	Quercus bicolor	Quercus gambelii	2004	130	6	2	0	0	3	0	0	0
05-855-1	Quercus muehlenbergii	Quercus geminata mix	2005	529	8	3	0	0	4	2	0	0
05-855-50	Quercus muehlenbergii	Quercus geminata mix	2005	629	11	7	0	1	10	0	0	1
05-805-1	Quercus montana	Quercus geminata mix	2005	129	11	3	4	0	4	1	3	0
05-805-2	Quercus montana	Quercus geminata mix	2005	129	13	8	2	0	5	0	3	0
05-904-2	Quercus macrocarpa 'Ashworth Strain'	Quercus geminata mix	2005	629	5	2	0	0	6	2	2	0
05-811-1	Quercus bicolor	Quercus geminata mix	2005	429	6	1	2	0	6	2	1	0
05-822-1	Quercus bicolor	Quercus geminata mix	2005	529	3	3	0	0	7	3	0	0
06-1802-1	Quercus bicolor	Quercus glauca	2006	128	4	3	0	0	4	1	1	0
05-812-1	Quercus bicolor	Quercus graciliformis	2005	127	7	2	3	0	8	0	1	0
06-1746-10	Quercus bicolor	Quercus graciliformis	2006	127	8	1	0	0	3	1	0	0
06-1746-11	Quercus bicolor	Quercus graciliformis	2006	127	11	5	1	0	5	0	0	0
06-1746-12	Quercus bicolor	Quercus graciliformis	2006	127							0	

Tree ID	Female Parent	Male Parent	Year	Hybrid Code	09 Shoots	09 Dead	09 Rooted	09 Mildew	10 Shoots	10 Dead	10 Rooted	10 Mildew
06-1746-3	Quercus bicolor	Quercus graciliformis	2006	127	7	4	1	1	5	0	0	1
06-1746-4	Quercus bicolor	Quercus graciliformis	2006	127	10	9	0	0	6	0	1	0
06-1746-6	Quercus bicolor	Quercus graciliformis	2006	127	8	2	0	0	7	1	0	0
06-1746-8	Quercus bicolor	Quercus graciliformis	2006	127	5	0	0	0	3	0	1	0
06-1746-9	Quercus bicolor	Quercus graciliformis	2006	127	8	2	6	0	4	2	1	0
06-1815-1	Quercus bicolor	Quercus graciliformis	2006	127	3	2	0	0	1	0	0	0
06-1814-1	Quercus bicolor	Quercus libani	2006	126	6	4	0	0	6	0	0	0
06-1814-2	Quercus bicolor	Quercus libani	2006	126	3	0	3	0	5	0	1	0
06-1814-3	Quercus bicolor	Quercus libani	2006	126	5	2	1	0				
05-856-1	Quercus muehlenbergii	Quercus lyrata	2005	125	21	15	0	0	4	0	0	0
05-874-2	Quercus muehlenbergii	Quercus lyrata	2005	225	7	1	0	0	3	3	0	0
05-874-3	Quercus muehlenbergii	Quercus lyrata	2005	225	5	1	2	0	2	0	0	0
05-806-1	Quercus montana	Quercus lyrata	2005	125	2	0	0	0	7	0	1	0
05-903-1	Quercus macrocarpa 'Ashworth Strain'	Quercus lyrata	2005	325	10	8	0	1	4	2	0	0
05-903-3	Quercus macrocarpa 'Ashworth Strain'	Quercus lyrata	2005	425	7	2	0	0	6	1	0	0
05-903-50	Quercus macrocarpa 'Ashworth Strain'	Quercus lyrata	2005	425	8	4	0	1	3	3	0	1
06-1820-1	Quercus macrocarpa	Quercus lyrata	2006	625	1	0	0	0				
06-1817-1	Quercus gambelii x macrocarpa	Quercus lyrata	2006	625	9	6	3	0	2	0	0	0
06-1819-1	Quercus gambelii x macrocarpa	Quercus lyrata	2006	625	10	8	0	0	17	1	15	1
06-1639-1	Quercus bicolor	Quercus lyrata	2006	425	2	0	0	0	2	0	0	0
06-1732-1	Quercus bicolor	Quercus lyrata	2006	525	7	2	0	0	9	1	0	0
06-1737-1	Quercus bicolor	Quercus macranthera	2006	124	2	0	1	0	2	0	0	0
04-571 -1 -1	Quercus macrocarpa	Quercus macrocarpa	2004	311								
04-571-1	Quercus macrocarpa	Quercus macrocarpa	2004	311	4	0	0	0	4	0	3	0
04-571-2	Quercus macrocarpa	Quercus macrocarpa	2004	311	5	2	1	0	2	0	1	0
04-571-2-1	Quercus macrocarpa	Quercus macrocarpa	2004	311	3	2	0	0				

Tree ID	Female Parent	Male Parent	Year	Hybrid Code	09 Shoots	09 Dead	09 Rooted	09 Mildew	10 Shoots	10 Dead	10 Rooted	10 Mildew
06-1673-1	Quercus macrocarpa	Quercus macrocarpa	2006	711	3	0	3	0	3	0	1	0
06-1673-2	Quercus macrocarpa	Quercus macrocarpa	2006	711	4	0	1	1	4	1	1	0
06-1673-3	Quercus macrocarpa	Quercus macrocarpa	2006	711	5	2	3	0	6	0	3	0
06-1673-4	Quercus macrocarpa	Quercus macrocarpa	2006	711	13	5	8	0	9	0	8	1
06-1673-5	Quercus macrocarpa	Quercus macrocarpa	2006	711	7	2	3	0	7	0	0	0
06-1673-6	Quercus macrocarpa	Quercus macrocarpa	2006	711	7	3	2	0	4	0	0	0
06-1673-7	Quercus macrocarpa	Quercus macrocarpa	2006	711	3	3	0	0	4	4	0	0
06-1673-8	Quercus macrocarpa	Quercus macrocarpa	2006	711	7	2	2	0	5	2	3	0
mac	Quercus macrocarpa	Quercus macrocarpa		323	6	2	1	0	4	0	1	0
04-567-1	Quercus bicolor	Quercus mexican sp. Plant Delights	2004	122	8	2	0	0	1	0	0	0
04-567-1-4	Quercus bicolor	Quercus mexican sp. Plant Delights	2004	122	4	0	1	0	4	0	0	0
04-567-2	Quercus bicolor	Quercus mexican sp. Plant Delights	2004	122	6	1	3	0	3	0	2	0
06-1612-1	Quercus muehlenbergii	Quercus michauxii	2006	621	7	3	0	0	3	0	0	0
06-1612-2	Quercus muehlenbergii	Quercus michauxii	2006	621	6	5	0	0	1	0	0	0
06-1612-9	Quercus muehlenbergii	Quercus michauxii	2006	621	9	7	0	0	3	0	0	1
05-905-1	Quercus macrocarpa 'Ashworth Strain'	Quercus michauxii	2005	421	4	2	0	0	3	3	1	0
05-905-2	Quercus macrocarpa 'Ashworth Strain'	Quercus michauxii	2005	421	6	4	0	0	6	3	1	0
05-905-3	Quercus macrocarpa 'Ashworth Strain'	Quercus michauxii	2005	421	6	2	1	0	2	2	0	0
05-857-1	Quercus muehlenbergii	Quercus minima	2005	420							0	
05-857-2	Quercus muehlenbergii	Quercus minima	2005	620	2	1	0	0	6	3	0	0
05-857-3	Quercus muehlenbergii	Quercus minima	2005	620	5	2	0	0	6	0	0	0
05-957-1	Quercus muehlenbergii	Quercus minima	2005	620					6	1	3	0
05-906-3	Quercus macrocarpa 'Ashworth Strain'	Quercus minima	2005	620	7	1	6	0	5	0	1	0
04-564-1	Quercus bicolor	Quercus minima	2004	120	5	3	0	0	1	0	0	0
04-564-1-2	Quercus bicolor	Quercus minima	2004	120	4	3	0	0	1	0	0	0

Tree ID	Female Parent	Male Parent	Year	Hybrid Code	09 Shoots	09 Dead	09 Rooted	09 Mildew	10 Shoots	10 Dead	10 Rooted	10 Mildew
04-564-1-4	Quercus bicolor	Quercus minima	2004	120	1	0	1	0	3	0	0	0
04-564-1-5	Quercus bicolor	Quercus minima	2004	120	7	1	0	0				
05-827-1	Quercus bicolor	Quercus minima	2005	120	4	2	0	0	8	1	0	0
06-1735-1	Quercus bicolor	Quercus mongolica grosserata	2006	119	3	3	0	0	2	0	0	0
06-1735-2	Quercus bicolor	Quercus mongolica grosserata	2006	119	9	2	0	0				
05-712-2	Quercus muehlenbergii	Quercus muehlenbergii	2005	311	10	5	0	1	4	0	1	0
04-566-1	Quercus bicolor	Quercus muehlenbergii	2004	118	6	1	2	0	5	0	1	0
04-566-1-1	Quercus bicolor	Quercus muehlenbergii	2004	118	4	3	0	0				
04-566-1-2	Quercus bicolor	Quercus muehlenbergii	2004	118	6	4	0	0				
04-566-1-3	Quercus bicolor	Quercus muehlenbergii	2004	118	3	3	0	0				
04-566-1-5	Quercus bicolor	Quercus muehlenbergii	2004	118	4	1	0	0				
04-566-2	Quercus bicolor	Quercus muehlenbergii	2004	118	5	1	5	0	3	0	0	0
04-566-2-1	Quercus bicolor	Quercus muehlenbergii	2004	118	8	3	0	0				
04-566-2-2	Quercus bicolor	Quercus muehlenbergii	2004	118	5	1	0	0				
04-566-2-3	Quercus bicolor	Quercus muehlenbergii	2004	118	7	4	0	0				
04-566-2-4	Quercus bicolor	Quercus muehlenbergii	2004	118	6	2	0	0				
04-566-3	Quercus bicolor	Quercus muehlenbergii	2004	118	7	2	5	1	3	2	0	0
04-566-3-1	Quercus bicolor	Quercus muehlenbergii	2004	118	5	2	0	0				
04-566-3-2	Quercus bicolor	Quercus muehlenbergii	2004	118	5	4	0	0				
04-566-3-3	Quercus bicolor	Quercus muehlenbergii	2004	118	3	1	0	0				
04-566-3-4	Quercus bicolor	Quercus muehlenbergii	2004	118	4	2	0	0				

Tree ID	Female Parent	Male Parent	Year	Hybrid Code	09 Shoots	09 Dead	09 Rooted	09 Mildew	10 Shoots	10 Dead	10 Rooted	10 Mildew
04-566-3-5	Quercus bicolor	Quercus muehlenbergii	2004	118	2	0	0	0				
04-566-4	Quercus bicolor	Quercus muehlenbergii	2004	118	4	2	0	0	3	0	0	0
04-566-4-1	Quercus bicolor	Quercus muehlenbergii	2004	118								
04-566-4-2	Quercus bicolor	Quercus muehlenbergii	2004	118	6	4	0	0	2	0	0	0
06-1629-1	Quercus bicolor	Quercus muehlenbergii	2006	118	6	2	2	0	5	2	1	0
06-1629-2	Quercus bicolor	Quercus muehlenbergii	2006	118	7	4	0	0	4	1	1	0
06-1801-1	Quercus bicolor	Quercus muehlenbergii	2006	118	4	0	4	0	4	0	0	1
06-1734-1	Quercus bicolor	Quercus muehlenbergii x robur	2006	117	4	2	0	0	4	2	3	0
06-1734-2	Quercus bicolor	Quercus muehlenbergii x robur	2006	117	5	3	2	0	5	0	2	1
06-1809-1	Quercus bicolor	Quercus muehlenbergii x robur	2006	117	5	1	1	0	4	3	0	0
04-565-1	Quercus bicolor	Quercus myrsinifolia	2004	116	5	3	1	0	4	0	1	1
04-565-1-1	Quercus bicolor	Quercus myrsinifolia	2004	116	8	3	0	0	1	0	0	0
04-565-1-2	Quercus bicolor	Quercus myrsinifolia	2004	116	2	0	2	0	1	0	0	0
04-565-1-3	Quercus bicolor	Quercus myrsinifolia	2004	116	4	2	0	0	2	0	1	0
04-565-1-4	Quercus bicolor	Quercus myrsinifolia	2004	116	3	1	0	0				
04-565-2	Quercus bicolor	Quercus myrsinifolia	2004	116	2	1	0	0	1	0	0	0
04-565-2-1	Quercus bicolor	Quercus myrsinifolia	2004	116	2	1	0	0	1	0	0	0
04-565-2-2	Quercus bicolor	Quercus myrsinifolia	2004	116	2	1	1	0	2	0	0	0
04-565-2-3	Quercus bicolor	Quercus myrsinifolia	2004	116	7	2	0	0	1	1	0	0
06-1748-1	Quercus bicolor	Quercus myrsinifolia	2006	116	4	1	0	0	2	0	0	0
06-1748-10	Quercus bicolor	Quercus myrsinifolia	2006	116	3	2	0	0	1	1	0	1
06-1748-11	Quercus bicolor	Quercus myrsinifolia	2006	116	10	5	0	0	5	0	0	0
06-1748-2	Quercus bicolor	Quercus myrsinifolia	2006	116	7	6	0	0	2	0	0	0
06-1748-3	Quercus bicolor	Quercus myrsinifolia	2006	116	1	0	1	0	1	0	0	0

Tree ID	Female Parent	Male Parent	Year	Hybrid Code	09 Shoots	09 Dead	09 Rooted	09 Mildew	10 Shoots	10 Dead	10 Rooted	10 Mildew
06-1748-4	Quercus bicolor	Quercus myrsinifolia	2006	116	17	7	2	0	9	2	0	0
06-1748-5	Quercus bicolor	Quercus myrsinifolia	2006	116	8	2	0	0	4	0	3	0
06-1748-6	Quercus bicolor	Quercus myrsinifolia	2006	116	12	8	0	0	8	1	1	0
06-1748-7	Quercus bicolor	Quercus myrsinifolia	2006	116	3	0	0	0	4	1	1	0
06-1748-8	Quercus bicolor	Quercus myrsinifolia	2006	116	8	6	0	0	5	0	0	1
06-1720-1	Quercus bicolor	Quercus phillyreoides	2006	115	3	0	1	0	5	1	0	0
06-1720-2	Quercus bicolor	Quercus phillyreoides	2006	115				0	2	0	1	0
06-1720-3	Quercus bicolor	Quercus phillyreoides	2006	115	6	4	0	0	3	0	0	1
06-1720-4	Quercus bicolor	Quercus phillyreoides	2006	115	2	1	0	0	1	0	0	0
06-1720-6	Quercus bicolor	Quercus phillyreoides	2006	115					4	2	0	0
06-1720-7	Quercus bicolor	Quercus phillyreoides	2006	115	5	1	1	0	5	0	2	0
06-1720-8	Quercus bicolor	Quercus phillyreoides	2006	115	4	2	0	0	3	1	2	0
05-828-1	Quercus bicolor	Quercus polymorpha	2005	114	3	2	0	0	2	2	0	0
06-1743-1	Quercus bicolor	Quercus polymorpha	2006	114	6	5	0	0				
06-1743-3	Quercus bicolor	Quercus polymorpha	2006	114	9	6	0	0	7	0	0	0
06-1743-6	Quercus bicolor	Quercus polymorpha	2006	114	5	1	4	0	2	1	0	0
04-577-1	Quercus muehlenbergii	Quercus prinoides	2004	613	9	7	0	0	9	1	0	0
04-577-2-1	Quercus muehlenbergii	Quercus prinoides	2004	613								
04-577-2-2	Quercus muehlenbergii	Quercus prinoides	2004	613	2	0	0	0				
04-577-3	Quercus muehlenbergii	Quercus prinoides	2004	613	6	4	0	0	4	0	0	1
04-577-4	Quercus muehlenbergii	Quercus prinoides	2004	613	4	2	0	0	2	0	0	0
04-577-5	Quercus muehlenbergii	Quercus prinoides	2004	613	5	1	0	0	5	0	0	1
04-575-1	Quercus macrocarpa	Quercus prinoides	2004	313	2	1	1	0	2	0	0	0
04-575-1-1	Quercus macrocarpa	Quercus prinoides	2004	313	4	3	0	0				
04-575-1-2	Quercus macrocarpa	Quercus prinoides	2004	313	6	3	0	0				
04-575-1-3	Quercus macrocarpa	Quercus prinoides	2004	313	4	3	0	0				
04-575-2	Quercus macrocarpa	Quercus prinoides	2004	313					1	0	0	0
04-575-2-1	Quercus macrocarpa	Quercus prinoides	2004	313	3	3	0	0				

Tree ID	Female Parent	Male Parent	Year	Hybrid Code	09 Shoots	09 Dead	09 Rooted	09 Mildew	10 Shoots	10 Dead	10 Rooted	10 Mildew
04-575-2-2	Quercus macrocarpa	Quercus prinoides	2004	313	5	1	0	0				
04-575-3-1	Quercus macrocarpa	Quercus prinoides	2004	313								
04-575-3-2	Quercus macrocarpa	Quercus prinoides	2004	313	5	5	0	0				
04-575-3-4	Quercus macrocarpa	Quercus prinoides	2004	313								
04-575-4	Quercus macrocarpa	Quercus prinoides	2004	313	6	2	2	0	3	1	0	0
04-575-4-1	Quercus macrocarpa	Quercus prinoides	2004	313	4	2	0	0				
04-575-4-2	Quercus macrocarpa	Quercus prinoides	2004	313	4	3	0	0				
06-1648-1	Quercus bicolor	Quercus robur 'Pectinata'	2006	112	3	1	0	0	5	0	0	0
06-1654-1	Quercus bicolor	Quercus robur 'Pectinata'	2006	112	4	1	1	0	3	0	1	0
06-1747-1	Quercus bicolor	Quercus robur 'Pectinata'	2006	112	7	7	0	0	4	0	4	0
06-1747-2	Quercus bicolor	Quercus robur 'Pectinata'	2006	112	5	1	0	0	2	0	0	0
06-1747-3	Quercus bicolor	Quercus robur 'Pectinata'	2006	112	6	2	0	0	2	0	0	0
06-1747-4	Quercus bicolor	Quercus robur 'Pectinata'	2006	112	9	7	0	1	4	0	0	0
06-1747-5	Quercus bicolor	Quercus robur 'Pectinata'	2006	112	10	4	0	0	7	2	0	1
06-1747-6	Quercus bicolor	Quercus robur 'Pectinata'	2006	112	6	2	0	0	6	2	0	0
06-1747-7	Quercus bicolor	Quercus robur 'Pectinata'	2006	112	5	2	0	0	2	0	0	0
06-1747-8	Quercus bicolor	Quercus robur 'Pectinata'	2006	112	6	4	0	1	4	1	0	1
06-1750-1	Quercus bicolor	Quercus robur argentomarginata	2006	110	6	2	3	0	5	2	2	0
04-569-1	Quercus bicolor	Quercus robur aureum	2004	109	5	2	0	0	4	2	1	0
04-569-1-3	Quercus bicolor	Quercus robur aureum	2004	109	1	0	1	0	2	0	0	0
04-569-1-4	Quercus bicolor	Quercus robur aureum	2004	109	5	4	0	0				
04-569-1-5	Quercus bicolor	Quercus robur aureum	2004	109	3	2	0	0				

Tree ID	Female Parent	Male Parent	Year	Hybrid Code	09 Shoots	09 Dead	09 Rooted	09 Mildew	10 Shoots	10 Dead	10 Rooted	10 Mildew
05-830-1	Quercus bicolor	Quercus rugosa	2005	108	5	2	0	0	5	4	1	0
05-830-2	Quercus bicolor	Quercus rugosa	2005	108	10	5	1	0	5	4	1	1
05-830-50	Quercus bicolor	Quercus rugosa	2005	108	11	7	4	0	5	1	2	0
06-1744-1	Quercus bicolor	Quercus rugosa	2006	108	9	4	1	0	4	3	1	0
06-1744-2	Quercus bicolor	Quercus rugosa	2006	108	3	0	0	0	3	1	0	0
06-1744-3	Quercus bicolor	Quercus rugosa	2006	108	8	1	0	0	6	0	0	0
06-1744-4	Quercus bicolor	Quercus rugosa	2006	108	4	2	0	0	5	0	2	1
06-1744-5	Quercus bicolor	Quercus rugosa	2006	108	4	2	0	0	4	0	0	0
06-1744-6	Quercus bicolor	Quercus rugosa	2006	108	8	3	1	0	8	1	0	1
06-1746-5	Quercus bicolor	Quercus rugosa	2006	108	4	4	0	0	11	2	0	0
06-1813-1	Quercus bicolor	Quercus rugosa	2006	108	6	2	2	0	7	0	1	0
06-1813-2	Quercus bicolor	Quercus rugosa	2006	108	4	1	2	0	2	0	0	1
06-1813-3	Quercus bicolor	Quercus rugosa	2006	108	12	7	3	0	6	1	5	0
06-1813-4	Quercus bicolor	Quercus rugosa	2006	108	7	4	0	0	1	0	1	0
06-1730-1	Quercus bicolor	Quercus species	2006	107	5	4	0	0	2	0	2	0
06-1730-2	Quercus bicolor	Quercus species	2006	107	10	3	1	0	5	1	0	0
06-1730-3	Quercus bicolor	Quercus species	2006	107	7	2	0	0	5	0	0	0
06-1730-4	Quercus bicolor	Quercus species	2006	107	9	5	1	0	1	0	0	0
06-1730-5	Quercus bicolor	Quercus species	2006	107	7	2	2	0	6	0	0	0
06-1730-6	Quercus bicolor	Quercus species	2006	107	6	4	0	0	4	2	3	0
06-1730-7	Quercus bicolor	Quercus species	2006	107	5	3	0	0	2	0	0	0
06-1730-8	Quercus bicolor	Quercus species	2006	107	2	1	0	0	3	0	1	1
06-1807-1	Quercus bicolor	Quercus species	2006	107	6	4	0	0	5	3	0	0
06-1729-1	Quercus bicolor	Quercus spinosa	2006	107	2	0	0	0	3	0	0	0
06-1729-5	Quercus bicolor	Quercus spinosa	2006	107	7	2	1	0	5	0	0	1
04-572-1	Quercus macrocarpa	Quercus turbinella	2004	306	8	2	0	0	6	0	1	0
04-568-1	Quercus bicolor	Quercus turbinella	2004	106	7	2	0	0	7	2	0	0
04-568-2	Quercus bicolor	Quercus turbinella	2004	106	12	10	1	0	6	0	1	0

Tree ID	Female Parent	Male Parent	Year	Hybrid Code	09 Shoots	09 Dead	09 Rooted	09 Mildew	10 Shoots	10 Dead	10 Rooted	10 Mildew
04-568-2-1	Quercus bicolor	Quercus turbinella	2004	106	2	0	1	0	2	0	0	0
04-568-2-4	Quercus bicolor	Quercus turbinella	2004	106	6	4	0	0	2	1	0	0
04-568-2-6	Quercus bicolor	Quercus turbinella	2004	106	7	2	0	0				
04-568-2-7	Quercus bicolor	Quercus turbinella	2004	106	4	3	0	0				
04-574-1	Quercus macrocarpa	Quercus undulata	2004	305	8	2	1	0	5	1	1	1
04-574-2	Quercus macrocarpa	Quercus undulata	2004	305	4	2	1	0	2	0	1	0
04-574-3	Quercus macrocarpa	Quercus undulata	2004	305	5	1	1	1	8	1	3	0
06-1633-1	Quercus bicolor	Quercus vaseyana	2006	104	3	0	2	0	2	1	2	0
06-1633-2	Quercus bicolor	Quercus vaseyana	2006	104	4	2	0	0	3	0	1	0
06-1726-1	Quercus bicolor	Quercus vaseyana	2006	104	5	4	0	0	6	1	0	0
06-1726-3	Quercus bicolor	Quercus vaseyana	2006	104	4	1	0	0	1	0	0	0
06-1726-4	Quercus bicolor	Quercus vaseyana	2006	104	5	2	1	0	5	0	0	1
06-1804-1	Quercus bicolor	Quercus vaseyana	2006	104	8	4	1	0	5	1	1	0
05-860-1	Quercus muehlenbergii	Quercus virginiana nc state	2005	603	9	5	0	1	4	0	1	1
05-860-2	Quercus muehlenbergii	Quercus virginiana nc state	2005	603	5	3	1	0	4	2	0	0
05-860-3	Quercus muehlenbergii	Quercus virginiana nc state	2005	603	15	7	0	0	5	0	0	1
05-878-1	Quercus muehlenbergii	Quercus virginiana nc state	2005	603	2	0	0	0	7	0	0	0
05-879-1	Quercus muehlenbergii	Quercus virginiana Taylor's	2005	602	5	3	0	0	3	2	0	0
05-879-2	Quercus muehlenbergii	Quercus virginiana Taylor's	2005	602	8	6	0	0	2	2	0	0
05-879-3	Quercus muehlenbergii	Quercus virginiana Taylor's	2005	602	3	2	0	0	7	3	0	0
06-1800-1	Quercus xwarei 'Long' REGAL PRINCE	Quercus x comptoniae	2006	201	11	4	5	1	7	0	2	1
06-1800-10	Quercus xwarei 'Long' REGAL PRINCE	Quercus x comptoniae	2006	301	9	3	1	0	4	0	1	0
06-1800-11	Quercus xwarei 'Long' REGAL PRINCE	Quercus x comptoniae	2006	601	6	1	3	1	9	0	2	1
06-1800-12	Quercus xwarei 'Long' REGAL PRINCE	Quercus x comptoniae	2006	701	7	3	0	0	5	1	1	1

Tree ID	Female Parent	Male Parent	Year	Hybrid Code	09 Shoots	09 Dead	09 Rooted	09 Mildew	10 Shoots	10 Dead	10 Rooted	10 Mildew
06-1800-13	Quercus xwarei 'Long' REGAL PRINCE	Quercus x comptoniae	2006	701	6	1	4	1	5	0	4	0
06-1800-14	Quercus xwarei 'Long' REGAL PRINCE	Quercus x comptoniae	2006	701	7	2	3	0	3	1	1	0
06-1800-15	Quercus xwarei 'Long' REGAL PRINCE	Quercus x comptoniae	2006	701	8	6	0	0	6	0	0	1
06-1800-16	Quercus xwarei 'Long' REGAL PRINCE	Quercus x comptoniae	2006	701	6	4	2	0	4	1	3	0
06-1800-17	Quercus xwarei 'Long' REGAL PRINCE	Quercus x comptoniae	2006	701	4	2	2	0	6	0	4	0
06-1800-2	Quercus xwarei 'Long' REGAL PRINCE	Quercus x comptoniae	2006	701	6	1	1	0	3	0	2	0
06-1800-3	Quercus xwarei 'Long' REGAL PRINCE	Quercus x comptoniae	2006	701	6	2	3	0	7	0	0	1
06-1800-4	Quercus xwarei 'Long' REGAL PRINCE	Quercus x comptoniae	2006	701	25	11	6	0	7	3	0	1
06-1800-5	Quercus xwarei 'Long' REGAL PRINCE	Quercus x comptoniae	2006	701	8	3	5	0	5	0	1	1
06-1800-6	Quercus xwarei 'Long' REGAL PRINCE	Quercus x comptoniae	2006	701	4	2	0	0	2	0	0	0
06-1800-7	Quercus xwarei 'Long' REGAL PRINCE	Quercus x comptoniae	2006	701	3	3	0	0	4	1	3	0
06-1800-8	Quercus xwarei 'Long' REGAL PRINCE	Quercus x comptoniae	2006	701	13	2	9	0	6	0	4	1
06-1800-9	Quercus xwarei 'Long' REGAL PRINCE	Quercus x comptoniae	2006	701	5	0	2	0	6	2	2	1
06-1613-3	Quercus muehlenbergii	Quercus x comptoniae	2006	201	1	0	1	0				
06-1821-3	Quercus macrocarpa	Quercus x comptoniae	2006	701	4	1	2	0	3	0	0	0
06-1818-1	Quercus gambelii x macrocarpa	Quercus x comptoniae	2006	701	10	6	4	0	2	0	2	0
06-1818-2	Quercus gambelii x macrocarpa	Quercus x comptoniae	2006	701	5	3	1	0	3	0	1	1
06-1500-1	Quercus xwarei 'Long' REGAL PRINCE	Quercus xwarei 'Long' REGAL PRINCE	2006	311	10	2	6	0	5	0	1	1
06-1500-2	Quercus xwarei 'Long' REGAL PRINCE	Quercus xwarei 'Long' REGAL PRINCE	2006	311	4	2	2	0	4	0	1	0
06-1500-3	Quercus xwarei 'Long' REGAL PRINCE	Quercus xwarei 'Long' REGAL PRINCE	2006	311	6	4	0	0	1	0	0	0

Tree ID	Female Parent	Male Parent	Year	Hybrid Code	09 Shoots	09 Dead	09 Rooted	09 Mildew	10 Shoots	10 Dead	10 Rooted	10 Mildew
06-1500-4	Quercus xwarei 'Long' REGAL PRINCE	Quercus xwarei 'Long' REGAL PRINCE	2006	311	5	0	5	1	4	0	3	1
06-1500-5	Quercus xwarei 'Long' REGAL PRINCE	Quercus xwarei 'Long' REGAL PRINCE	2006	311	2	1	1	0	4	0	4	0
06-1500-6	Quercus xwarei 'Long' REGAL PRINCE	Quercus xwarei 'Long' REGAL PRINCE	2006	311	7	1	3	0	5	0	4	0
06-1500-7	Quercus xwarei 'Long' REGAL PRINCE	Quercus xwarei 'Long' REGAL PRINCE	2006	311	4	0	4	0	5	2	3	1
06-1500-8	Quercus xwarei 'Long' REGAL PRINCE	Quercus xwarei 'Long' REGAL PRINCE	2006	611	8	5	1	1	2	0	2	1

Table 17. Original data of SPAD reading on hybrid oaks propagated in 2010.

Plant Code	**Female Parent**	**Male Parent**	**May SPAD**	**June SPAD**	**May SPAD**	**June SPAD**
			High pH		Low pH	
04-560-3	Quercus bicolor	Quercus bicolor	28.7	29.1	35.0	37.0
04-560-5	Quercus bicolor	Quercus bicolor	27.5	34.8	29.2	33.4
06-1730-1	Quercus bicolor	Quercus bicolor	N/A	14.8	31.6	32.1
04-566-1	Quercus bicolor	Quercus muehlenbergii	26.2	30.3	28.7	35.4
06-1720-7	Quercus bicolor	Quercus phillyreoides	20.4	16.9	24.6	29.5
06-1813-3	Quercus bicolor	Quercus rugosa	22.4	28.8	25.3	25.7
06-1747-1	Quercus bicolor	Quercus robur 'Pectinata'	24.1	33.1	24.1	36.2
06-1819-1	Quercus gambelii x macrocarpa	Quercus lyrata	29.7	29.2	30.6	30.3
04-571-1	Quercus macrocarpa	Quercus macrocarpa	20.9	28.3	29.3	34.7
04-576-1	Quercus macrocarpa	Quercus gambelii	28.8	31.7	32.2	34.4
04-576-3	Quercus macrocarpa	Quercus gambelii	26.5	30.5	31.4	32.9
06-1673-8	Quercus macrocarpa	Quercus macrocarpa	29.9	40.7	33.7	42.4
05-906-3	Quercus macrocarpa 'Ashworth Strain'	Quercus minima	33.8	36.5	42.6	39.3
05-805-1	Quercus montana	Quercus geminata mix	22.2	30.6	37.8	32.9
06-1800-17	Quercus xwarei 'Long' REGAL PRINCE	Quercus x comptoniae	34.6	42.5	36.7	45.1
06-1800-13	Quercus xwarei 'Long' REGAL PRINCE	Quercus x comptoniae	33.1	37.2	35.0	37.2
06-1500-5	Quercus xwarei 'Long' REGAL PRINCE	Quercus xwarei 'Long' REGAL PRINCE	23.0	29.1	31.7	34.7
06-1500-6	Quercus xwarei 'Long' REGAL PRINCE	Quercus xwarei 'Long' REGAL PRINCE	29.4	28.5	26.2	34.3
Average of the whole treatment group			**27.9**	**30.4**	**31.4**	**34.1**

Table 18. Original data of SPAD reading on hybrid oaks propagated in 2009.

Plant Code	**Female Parent**	**Male Parent**	**May SPAD**	**June SPAD**	**May SPAD**	**June SPAD**
			High pH		Low pH	
04-567-2	Quercus bicolor	Quercus mexican sp. Plant Delights	34	9.8	36.3	31.8
04-560-3	Quercus bicolor	Quercus bicolor	***34.25***	***26.2***	33	33.6
04-560-5	Quercus bicolor	Quercus bicolor	35.9	34.1	27.9	30.7
04-561-1	Quercus bicolor	Quercus bebiana	30.4	29.3	***35.45***	***28.85***
04-562-4	Quercus bicolor	Quercus aliena	29.3	26.7	***31.8***	***33.3***
04-565-1-4	Quercus bicolor	Quercus myrsinifolia	34.2	35.7	36.6	37
04-566-3	Quercus bicolor	Quercus muehlenbergii	***34.05***	***32.95***	***32.9***	***33.8***
05-830-50	Quercus bicolor	Quercus rugosa	***30.85***	***30.1***	28.2	26.7
06-1633-1	Quercus bicolor	Quercus vaseyana	30.8	4.9	N/A	N/A
06-1633-1	Quercus bicolor	Quercus vaseyana	30.5	28.3	34.2	27.8
06-1733-17	Quercus bicolor	Quercus aliena acuteserrata	42.4	44.5	40.2	39.4
06-1742-1	Quercus bicolor	Quercus fruticosa	34.8	39.5	35.7	27.9
06-1750-1	Quercus bicolor	Quercus robur argentomarginata	***30.6***	***30.25***	35.7	37.8
06-1810-2	Quercus bicolor	Quercus dentata pinnatifida	***28.0***	***30.9***	***31.7***	***34.6***
06-1811-3	Quercus bicolor	Quercus fabri	36.3	18.5	31.1	37.8
06-1814-2	Quercus bicolor	Quercus libani	46	31	33.5	37.1
04-576-1	Quercus macrocarpa	Quercus gambelii	***35.5***	***41.4***	***35.1***	***39.75***
04-576-3	Quercus macrocarpa	Quercus gambelii	***34.55***	***35.25***	***34.3***	***37.1***
06-1673-1	Quercus macrocarpa	Quercus macrocarpa	34.8	35.1	38.4	38.4
06-1673-3	Quercus macrocarpa	Quercus macrocarpa	27.9	26.7	31.5	32.3
06-1673-4	Quercus macrocarpa	Quercus macrocarpa	37.5	16.8	***37.9***	***37.6***
06-1673-8	Quercus macrocarpa	Quercus macrocarpa	30.3	24.7	45	46.3
05-906-3	Quercus macrocarpa 'Ashworth Strain'	Quercus minima	46	29.9	30.4	35.8
06-1500-1	Quercus xwarei 'Long' REGAL PRINCE	Quercus xwarei 'Long' REGAL PRINCE	18.9	15.8	***39.05***	***38.8***
06-1800-13	Quercus xwarei 'Long' REGAL PRINCE	Quercus x comptoniae	***33.0***	***37.4***	37.7	40.8
06-1818-1	Quercus gambelii x macrocarpa	Quercus x comptoniae	***35.6***	***30.55***	39.1	37.9
Average of the whole treatment group			**32.7**	**29.7**	**35.3**	**35.7**

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